View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Elsevier - Publisher Connector

Available online at www.sciencedirect.com
ScienceDirect
Procedia Technology 23 (2016) 217 – 224
Procedia Technology

3rd International Conference on Innovations in Automation and Mechatronics Engineering, ICIAME 2016

Vibration diagnosis and prognostics of Turn-milling operations using HSS and carbide end mill cutters

K. Arun Vikram[a]*, Ch. Ratnam[b] and K. Sankar Narayana[a]

[a]*GITAM Institute of Technology, GITAM University, Visakhapatnam, Andhra Pradesh, India 530045.*
[b]*Andhra University College of Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India 530003*

Abstract

Vibrations are the leading phenomenon in analyzing surface finish and machine condition. The present work focuses on effect of machining parameters on Surface Roughness (Ra) and Tool Vibrations (VIB) in manufacturing operational methods like tangential and orthogonal turn-milling processes. Single cut machining on A-axis of CNC Vertical Milling centre using HSS and carbide end mill cutters are adopted. Process parameters like cutter (tool) speed, feed rate and depth of cut with constant rotation of workpiece on A-axis are chosen while machining Extruded brass material under dry condition. Statically design experiments based on Taguchi's philosophy of Orthogonal Array (OA) is adopted for experimentation. Online capturing of Acousto-optic emissions (AOE) of tool shank vibrations is done using Laser Doppler Vibrometer (LDV) and is analyzed using VibSoft analyzer. Peak vibrations displacements of the cutting tool shanks are identified using Fast Fourier Transforms (FFT) over time domain signals and are used for vibration diagnosis and prognostics as a measure of machine tool condition monitoring, Failure Mode and Effective Analysis (FMECA) based on ISO standards is used for vibration prognostics.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of ICIAME 2016

Keywords: LDV; Prognostics; Roughness; Taguchi; turn-milling; Vibration diagnosis.

1. Introduction

Vibration monitoring and analysis can be performed based on over a period of creation or by analyzing the present working stature of the machine tool. For vibration analysis based on period of creation, one has to follow

* Corresponding author. Tel.: +0-891-284-0255; fax: +0-891-279-5312.
E-mail address: arunvikram@gmail.com

2212-0173 © 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of ICIAME 2016
doi:10.1016/j.protcy.2016.03.020

five stages viz. determining the initial condition, Monitoring, Detection, Analysis and recommendations which will be helpful for maintenance of the machine tool and its sub-assemblies. To measure the performance of a machine tool at a particular interval and to recommend maintenance, the vibrations of the machine tool has to be monitored in all frequency ranges (broad and narrow band widths). The maintenance recommendations based on broad band frequency range is termed to be “Diagnosis” as it presents the present extractions of the machining conditions and can be used to classify the different fault modes, while the recommendations based on narrow band frequency ranges is termed to “Prognostics” as it needs the extractions which can reflect the degradation process of the machine tool [1]. Vibration diagnosis and prognostics of machine tool is useful in adopting an adoptive control mechanism for machine tool condition monitoring. Undoubtedly, a machine tool comprises several sub-components assembly of the system including machine body, bearings, gears, spindle etc but the overall vibrations of the machine tool projects on workpiece surface roughness and cutting tool vibrations, thereby leading the importance of surface finish and cutting tool vibration monitoring.

Rotary tool mechanism is a concept of relative rotary motion between workpiece and cutting tool (i.e. end mill cutters) which produces considerably less drag force and vibrations. James Napier foresaw the advantages and commercial possibilities of rotary cutting tools in 1868[2]. After 80 years of period it got focused in 1950`s by Shaw and his co-workers and classified rotary cutting tools as self-propelled and active driven rotary tools. As time elapsed, the intensiveness in this area got focused, which was stopped due to complex kinematics between the rotary cutting tool and rotating workpiece. The concept of rotary cutting tool emerged a new direction for developing machine tool named as “Turn-Mill”, where in the milling rotary cutting tools and lathe workpiece rotations are combined [2-4].

Nakagawa et al.[5] proposed Laser Doppler Vibrometer (LDV) for capturing and analysis of high frequency chatter on coated cemented carbide end mill while machining hardened steels in feed and radial directions simultaneously and concluded the chatter vibrations to be vibration modes. Whereas, LDV is used for capturing online vibrations while machining AISI 1040 steel in boring and analyzed for optimal machining parameters in generating roughness, vibrations and metal removal rate. They reported the online tool wear estimation can be done indirectly using LDV by transforming the AOE signals of time domain on the tool into Frequency domain using Fast Fourier Transforms (FFT) [6].

The present work focus on surface finish and in addition, vibration analysis of A-axis vertical milling machine tool based on vibration diagnosis (i.e. based on broad band frequency band width) and prognostics (i.e. based on narrow frequency band widths) using ISO 13381-1 standards [7] and explore recommendations for better machine life, performance and reproducibility in tangential and orthogonal turn-milling processes using HSS cutters at normal speeds and tangential turn-milling process using carbide cutters at high speeds of the machine tool.

2. Experimentation Design and Methodology

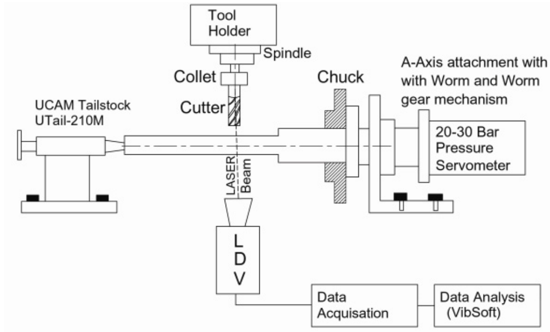
Extruded Brass (leaded) as per IS:319-2007-Grade:1 which has wider application in the manufacture of various items like Architecture, Extrusions, Thresholds, Butt Hinges, Locks Bodies, Screws, Nuts, Bolts and Hardware, etc [8] is taken as work piece material for singe cut turning operation in turn-milling processes. Commercially available High Speed Steel (HSS) end mill cutters as per BS: 122-1953 of ADDISON Company and carbide end mill cutters of MSG-USA with each 10mm diameter-30^0 helix long parallel shank are used as cutting tools under dry conditions.

2.1 Experimentations setup

Cylindrical work piece material of 40mm diameter and length 225mm was divided into 5 parts on length as 4x 40mm and 65mm extra length for avoiding tool holder hitting the A-axis chuck of CNC Vertical Milling centre of Jyothi makes with spindle speed of 50-8000rpm and is shown in Fig.1a and Fig.1b. MITUTOYO Surface Test SJ-301 with Stylus (Diamond) differential induction method detection unit is used for measuring Surface Roughness (Ra) at offline, while LDV of PolyTech-PVD100 is used for capturing online AOE over the cutting tool shanks.

2.2. Taguchi Design of Experiments

Taguchi Design of Experiments (DOE) widely used in many industries to efficiently optimize the manufacturing process [4,6] is adopted in the present study with four levels of three process parameters viz. tool speed, feed rate and depth of cut generating 16 (L_{16}) experiments based on orthogonal arrays, as shown in Table 1.



(a) VMC-1050 with A-axis attachment and LDV (b) Schematic representation of experimental setup

Fig.1. Experimental setup

Table 1. Taguchi DOE of L_{16} based on Orthogonal Array.

Exp. No.	Machining Parameters			Actual setting values for HSS cutting tool machining in Tangential and Orthogonal Turn-milling process			Actual setting values for carbide cutting tool machining in Tangential Turn-milling process		
	A	B	C	A: Tool Speed (rpm)	B: Feed Rate (mm/min)	C: Depth of Cut (mm)	A: Tool Speed (rpm)	B: Feed Rate (mm/min)	C: Depth of Cut (mm)
1	1	1	1	2400	3.27	0.25	5500	3.27	0.25
2	1	2	2	2400	5.05	0.50	5500	5.05	0.50
3	1	3	3	2400	8.76	0.75	5500	8.76	0.75
4	1	4	4	2400	10.0	1.00	5500	10.0	1.00
5	2	1	2	2650	3.27	0.50	5750	3.27	0.50
6	2	2	1	2650	5.05	0.25	5750	5.05	0.25
7	2	3	4	2650	8.76	1.00	5750	8.76	1.00
8	2	4	3	2650	10.0	0.75	5750	10.0	0.75
9	3	1	3	2900	3.27	0.75	6000	3.27	0.75
10	3	2	4	2900	5.05	1.00	6000	5.05	1.00
11	3	3	1	2900	8.76	0.25	6000	8.76	0.25
12	3	4	2	2900	10.0	0.50	6000	10.0	0.50
13	4	1	4	3150	3.27	1.00	6250	3.27	1.00
14	4	2	3	3150	5.05	0.75	6250	5.05	0.75
15	4	3	2	3150	8.76	0.50	6250	8.76	0.50
16	4	4	1	3150	10.0	0.25	6250	10.0	0.25

2.3 Experimental methodology

The process parameters like tool speed, feed rate and depth of cut with 20rpm constant rotation of workpiece is considered in all the turn-milling processes for experimentation based on Taguchi DOE, as given in Table 1 and surface roughness (R_a) and cutting tool shank vibrations in time wave spectra are recorded as responses in plain single cut turning operation. For every tool speed, a new cutting tool was used for machining to avoid impact of tool wear and crater and experimental study was carried as shown in Fig.2.

The offline averaged surface roughness values are considered and in addition, as the signals in machine tool generates random signals [9], the peak vibrations displacements of the cutting tool shanks using FFT with Fourier analysis like Discrete Fourier Transform (DFT) over the time domain signals are used for diagnosis and prognostics of vibrations. The vibration signals over the cutting tool shanks are captured in time wave form for 50milli-seconds duration with 1200 samples and with a sampling frequency of 24Kilo-Hertz (KHz). The time domain is filtered with a low-pass filter less than the Nyquist frequency (<12 KHz) which is half of sampling frequency for avoiding stroboscopic effect [9]. To diagnose the vibration signals, the time wave form are transformed to frequency spectra. The anti-aliased time signal is filtered using a band-pass filter of broad band widths (which is the range of appearance of defects like bearing and gear faults etc related to the rotation of the tool and workpiece and narrow band widths (for prognostics) and later, the filtered time signal is transformed to frequency spectra using a Hanning window with 256 FFT lines for identifying the peak displacement values of the tool. The broad band width and narrow band width considered for transformation of the time spectra to frequency spectra while machining turn-milling operation using the HSS and carbide end mill cutters is listed in the Table 2. The sample vibration signatures in time and frequencies in broad band width ranges are shown in Fig. (3a)-(3d).

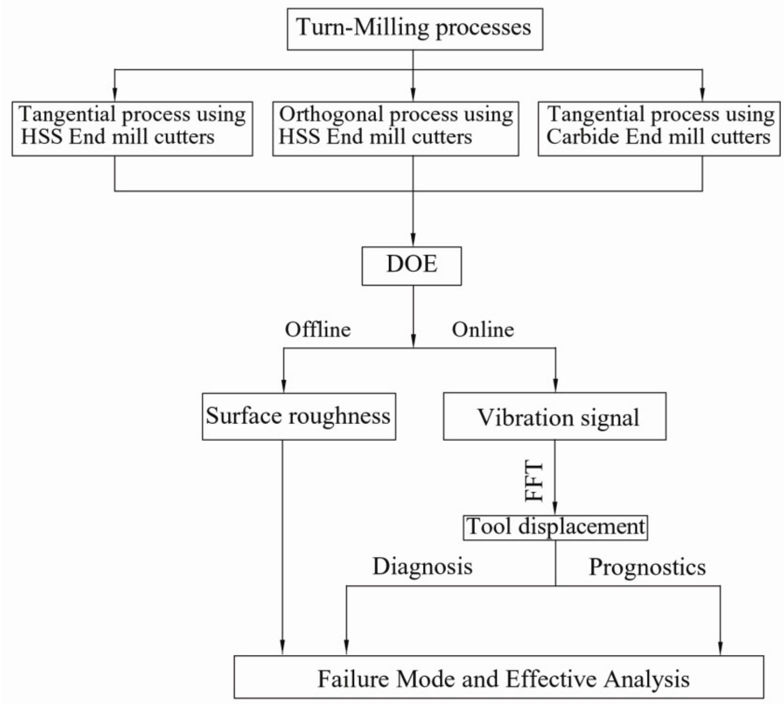
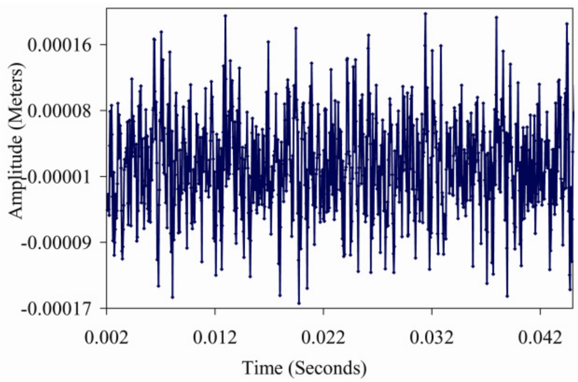


Fig.2. Experimentation Methodology

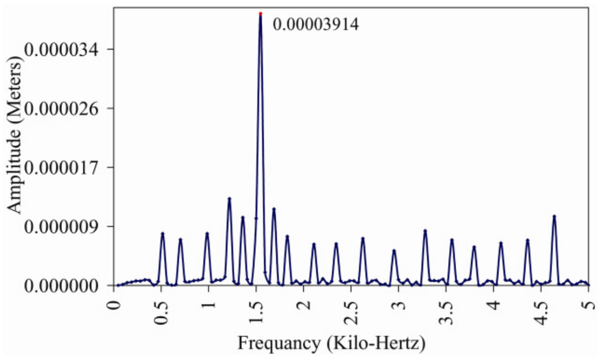
Table 2. Specification of broad band and narrow band widths

Type of end mill cutter	Type of turn-milling operation	Broad band width for identifying bearings and gear defects. (> 10X)	Narrow band width in sub-synchronous stage (<1X)	Narrow band width for identifying mechanical losses. (1x to 10X)
HSS	Tangential	500Hz-5000Hz	1Hz-50Hz	50Hz-500Hz
	Orthogonal			
Carbide	Tangential	1000Hz-10000Hz	1Hz-100Hz	100Hz-1000Hz

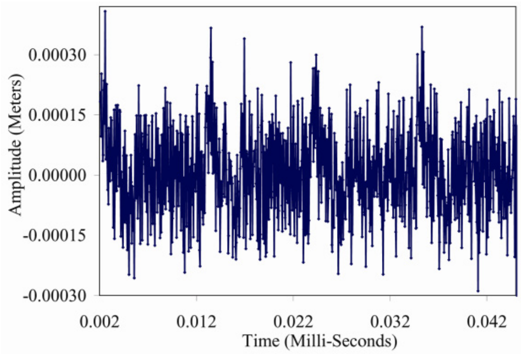
X: Rotational frequency of the tool



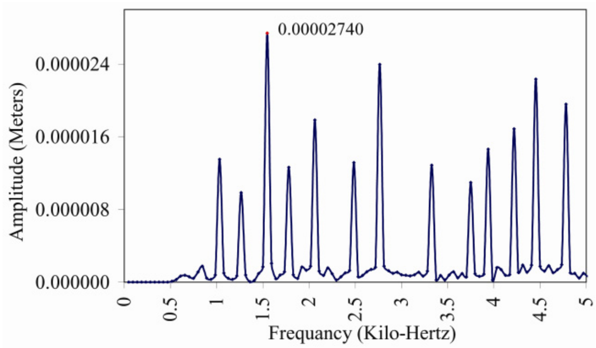
(a) Time wave form in orthogonal turn-milling using HSS cutter at 2400rpm



(b) Frequency wave form in orthogonal turn-milling using HSS cutter at 2400rpm



(c) Time wave form in tangential turn-milling using carbide cutter at 5500rpm



(d) Frequency wave form in tangential turn-milling using carbide cutter at 5500rpm

Fig.3. Time and frequency spectra's of experimental run 1 in broad band frequency range

3. Results

Graph plots for the first two predominant machining factors on the generated surface finish and tool displacement interpret, that the tool speeds increase surface finish and reduces tool displacement but at higher range of machine tool, the tool displacement increases with depth of cut. The optimal levels of cutting parameters were found to be **A4-B1-C1, A4-B1-C4 and A4-B1-C1** respectively. Basing on smallest-is-better quality characteristic of Taguchi`s SN ratios, the optimal average surface roughness were determined as 0.31micro-meters (µm), 2.1µm and 0.20µm in tangential and orthogonal machining with HSS and tangential machining with carbide respectively. While the optimal levels of cutting parameters were found as **A4-B2-C1, A4-B1-C1** and **A4-B2-C1** respectively and the optimal tool displacement amplitudes were determined as 13.56µm, 22.49µm and 27.28µm in tangential and orthogonal machining with HSS and tangential machining with carbide respectively.

4. Discussions and Conclusions

When compared tangential turn-milling over orthogonal turn-milling, the tangential turn-milling seems to generate good surface finish. While reaching the high speed ranges near to maximum capacity of the machine tool, the tool vibration increased due to instability and thereby the tool displacement became high and this phenomenon is observed.

The frequency spectra's shows different frequency modes which represent various mechanical components manifesting their vibrations at their specific frequency values like motor vibration, machine bed vibration, foundation etc. In tangential turn-milling, the laser beam is perpendicular to the shearing action of the rotating tool and rotating workpiece and so the number of peaks in frequency spectra seems to have high number peaks resembling the effect of other components inclusion. Whereas in orthogonal turn-milling, the laser beams is in the direction of shearing action of the rotary tool and rotating workpiece and so a single high peak frequency spectra resembling the displacement of the tool is seen while the other components effects are low in peaks.

An attempt of prognostics basing on FMECA as per the ISO standards is being applied for studying the deviation of machine responses (viz. surface roughness and tool displacements) from the original values. The notations given below are used in framing the FMECA chart.

E_1: Machined surface E_2: Tool wear
FM_1: Surface finish FM_3: Tool vibrations
PE_1: Less frequent application of machine [10]
PE_2: Average application of machine [10]
TE_0: Tool is good working condition with no wear (ISO:2372)
TE_1: The tool wear seems to be starting and reflects on increase in roughness
TE_2: tool wear is high and so increases roughness
TE_3: Tool wear is high and distort the workpiece surface

In addition, FMECA is used to study the present status of the working conditions of the machine tool basing on the graph patterns of the recorded data and to implicate corrections for betterment of the response values and reproducibility, as shown in Table(s).3,4 and 5.

Table 3. FMECA of broad band frequency of 500-5000Hz in tangential process using HSS (for experimental runs with deviations only)

Exp. No:	R_a	VIB	Component	Failure mode	Effect on	PE	Detection values based on vibration amplitudes (As per ISO:2372)			Actions Recommended
							Alarm (< 20μm)	Alert (20μm to 60μm)	Trip (> 60μm)	
4	2.30	47.10	Workpiece	FM_1	E_1	PE_2	x	√	x	1. Tool to be re-grinded to reduce the VIB and R_a. 2. Check alignment of tool and workpiece.
			Tool	FM_1	E_2	TE_3				
6	0.73	21.50	Workpiece	FM_1	E_1	PE_1	x	√	x	Tool fixing and penetration into workpiece to be checked due to in-appropriate increase in responses.
			Tool	FM_3	E_2	TE_1				
7	1.80	31.20	Workpiece	FM_1	E_1	PE_2	x	√	x	
			Tool	FM_3	E_2	TE_2				
8	1.88	34.85	Workpiece	FM_1	E_1	PE_2	x	√	x	
			Tool	FM_3	E_2	TE_2				
11	1.08	19.91	Workpiece	FM_1	E_1	PE_2	√	x	x	
			Tool	FM_3	E_2	TE_0				
12	1.50	29.48	Workpiece	FM_1	E_1	PE_2	x	√	x	
			Tool	FM_3	E_2	TE_2				
14	0.42	16.40	Workpiece	FM_1	E_2	PE_1	√	x	x	Check tool-workpiece alignment due to in-appropriate decrease in R_a.
			Tool	FM_3	E_1	TE_0				
15	0.84	14.72	Workpiece	FM_1	E_2	PE_2	√	x	x	Tool fixing and alignment to be checked.
			Tool	FM_3	E_1	TE_0				
16	1.01	18.50	Workpiece	FM_1	E_2	PE_2	√	x	x	
			Tool	FM_3	E_1	TE_0				

Table 3a. FMECA of narrow-band frequency of 1-50Hz and 50-500Hz in tangential process using HSS (for experimental runs with deviations only)

Exp. No:	Vibrations Displacement in Narrow Bands (Microns)		Component	Failure mode	Effect on	Detected values based on vibration		Actions Recommended
	Synchronous (1Hz - 50Hz)	Mechanical Looseness (50Hz-500Hz)				Alarm (<20μm)	Alert (20μm- 60μm)	
3	0.35	25.66	Workpiece and Tool	FM_1 and FM_3	E_1 and E_2	-	√	Workpiece and Tool alignment and fixing to be checked
4	0.34	24.73						

Table 4. FMECA of broad band frequency of 500-5000Hz in orthogonal process using HSS (for experimental runs with deviations only)

Exp. No:	R_a	VIB	Component	Failure mode	Effect on	PE	Detected values based on vibration			Actions Recommended
							Alarm (< 20μm)	Alert (20μm to 60μm)	Trip (> 60μm)	
2	5.65	54.49	Workpiece	FM_1	E_1	PE_2	x	√	x	Tool to be re-grinded to reduce VIB and R_a.
			Tool	FM_1	E_2	TE_2				
3	6.50	71.30	Workpiece	FM_1	E_1	PE_2	x	x	√	Tool to be replaced due to high VIB and R_a which is due to tool wear.
			Tool	FM_1	E_2	TE_3				
4	7.30	80.21	Workpiece	FM_1	E_1	PE_2	x	x	√	
			Tool	FM_1	E_2	TE_3				
6	5.35	32.30	Workpiece	FM_1	E_1	PE_1	x	√	x	Tool and workpiece penetration to be checked.
			Tool	FM_3	E_2	TE_1				
7	5.93	71.64	Workpiece	FM_1	E_1	PE_2	x	x	√	Tool alignment and assembly to be checked, as the R_a is appropriate
			Tool	FM_3	E_2	TE_2				
8	7.12	52.50	Workpiece	FM_1	E_1	PE_2	x	√	x	Tool to be re-grinded to reduce VIB and R_a.
			Tool	FM_3	E_2	TE_2				

10	4.10	65.50	Workpiece	FM_1	E_1	PE_1	x	x	√	Tool and workpiece alignments to be checked due to high VIB and increased R_a.
			Tool	FM_3	E_2	TE_1				
11	5.50	31.50	Workpiece	FM_1	E_1	PE_2	x	√	x	Tool and workpiece alignments to be checked due to increased R_a.
			Tool	FM_3	E_2	TE_0				
12	6.18	38.90	Workpiece	FM_1	E_1	PE_2	x	√	x	
			Tool	FM_3	E_2	TE_2				
15	4.65	36.70	Workpiece	FM_1	E_2	PE_2	√	x	x	
			Tool	FM_3	E_1	TE_0				
16	5.70	22.30	Workpiece	FM_1	E_2	PE_2	√	x	x	
			Tool	FM_3	E_1	TE_0				

FMECA of narrow band frequency range of 1Hz-50Hz and 50Hz-500Hz in orthogonal process using HSS cutters shows no deviation of responses and hence recommends no failure modes, remedies and corrections.

Table 5. FMECA of broadband frequency of 1000-10000Hz in tangential process using carbide (for experimental runs with deviations only)

Exp. No:	R_a	VIB	Component	Failure mode	Effect on	Potential effect	Detected values based on vibration			Actions Recommended
							Alarm (<20µm)	Alert (20µm-60µm)	Trip (VIB> 60µm)	
3	1.22	28.93	Workpiece	FM_1	E_1	PE_2	x	√	x	Tool and workpiece alignments to be checked due to decreased roughness.
			Tool	FM_1	E_2	TE_1				
6	0.47	31.00	Workpiece	FM_1	E_1	PE_1	x	√	x	Tool alignment and fixing to be checked
			Tool	FM_3	E_2	TE_1				
7	1.04	32.30	Workpiece	FM_1	E_1	PE_2	x	√	x	
			Tool	FM_3	E_2	TE_1				
8	1.46	32.98	Workpiece	FM_1	E_1	PE_2	x	√	x	
			Tool	FM_3	E_2	TE_1				
10	0.46	39.98	Workpiece	FM_1	E_2	PE_1	x	√	x	Tool and workpiece alignments to be checked due to decreased roughness.
			Tool	FM_3	E_1	TE_1				
14	0.39	45.40	Workpiece	FM_1	E_2	PE_1	x	√	x	Tool fixing and alignment to be checked
			Tool	FM_3	E_1	TE_2				

Table 5a. FMECA of narrow-band frequency of 1-100Hz and 100-1000Hz in tangential process using carbide (for experimental runs with deviations only)

Exp. No:	Vibrations Displacement in Narrow Bands (Microns)		Component	Failure mode	Effect on	Detected values based on vibration		Actions Recommended
	Synchronous (1Hz - 100Hz)	Mechanical Looseness (100Hz-1000Hz)				Alarm (0µm-60 µm)	Alert (> 60µm)	
7	2.03	65.81	Workpiece and Tool	FM_1 and FM_3	E_1 and E_2	-	√	Workpiece and Tool alignment and fixing to be checked
11	1.56	65.14						

References

[1] Zhang X., Kang J., Zhao J.S., Cao D.C. Features for fault diagnosis and prognosis of gearbox. Chemical Engineering Transactions, Vol.33, p.1027,2013. DOI: 10.3303/CET1333172
[2] Choudhary SK, Bajpai JB. Investigation in Orthogonal Turn-Milling towards better surface finish. J. Mater Process Technol, Vol.170,p.487,2004.
[3] Vedat Savas, Cetin Ozay. Analysis of the surface roughness of tangential turn-milling for machining with end milling cutter. J. Mater Process Technol, Vol.186,p.279,2007.

[4] Vedat Savas, Cetin Ozay. The optimization of the surface roughness in the process of Tangential Turn-milling using genetic algorithm. Int J Adv Manuf Technol,Vol.37,p.335,2008.
[5] Nakagawa H, Kurita Y, Keiji Ogawa, Yuji Sugiyama and Hideyasu Hasegawa. Experimental Analysis of Chatter Vibration in End-Milling Using Laser Doppler Vibrometers, Int. J. of Automation Technology, Vol.2(6), 2008.
[6] Venkata Rao K, Murthy B.S.N, Mohan Rao N. Cutting tool condition monitoring by analyzing surface roughness, work piece vibration and volume of metal removed for AISI 1040 steel in boring. Measurement,Vol.46,p.4075,2013.
[7] Diego T.M, Medjaher K, Zerhouni N. The ISO 13381-1 Standard's failure prognostics process through an example. IEEE Prognostics and System Health Management Conference, IEEE Macau, PHM 2010, Macau,China.
[8] Arun Vikram K, Ratnam Ch, Sankara N.K, Satish B.B. Assessment of surface roughness and MRR while machining brass with HSS tool and carbide inserts. Indian J. Engg & Materials Sciences,Vol.22(3),p.321,2015.
[9] Clarence W. de Silva. Vibration Signal Analysis, in: Mechanical Engineering Series, Frank Krith, Vibration and Shock Handbook, Taylor and Francis Group, LLC, p.10.1,2005.
[10] Kalpakjian, Schmid. Manufacturing Processes for Engineering Materials, 5th ed., Pearson Education, 2008.